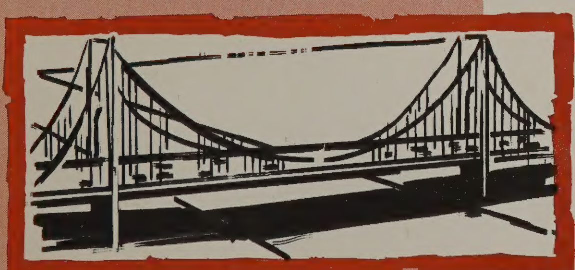
# STABILITY ANALYSIS

# SLOPES AND EMBANKMENT FOUNDATIONS



bureau of electronic data processing

ENGINEERING DATA PROCESSING SERIES

OCTOBER 1963

STATE OF NEW YORK

DEPARTMENT OF PUBLIC WORKS

# STABILITY ANALYSIS
# SLOPES AND EMBANKMENT FOUNDATIONS

PROGRAM NUMBER 5171

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BUREAU OF ELECTRONIC DATA PROCESSING

STABILITY ANALYSIS

SLOPES AND EMBANKMENT FOUNDATIONS

PROGRAM NUMBER 5171

## ACKNOWLEDGMENTS

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STABILITY ANALYSIS

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# STABILITY ANALYSIS
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### ABSTRACT

THE COMPUTER PROGRAM PRESENTED HERE CAN BE USED WITH THE IBM 1620 COMPUTER TO ANALYZE THE STABILITY OF CUT SLOPES, FILL SLOPES, AND EMBANKMENT FOUNDATIONS. CROSS-SECTIONS CONTAINING ANY IRREGULAR CONFIGURATION OF GROUND SURFACE AND SUBSOIL LAYERS THAT CAN BE APPROXIMATED BY TEN STRAIGHT LINES CAN BE ANALYZED. A FAILURE ARC AND A FACTOR OF SAFETY SUFFICIENTLY CLOSE FOR PRACTICAL PURPOSES TO THE MOST CRITICAL FAILURE ARC AND THE LOWEST FACTOR OF SAFETY ARE FOUND AUTOMATICALLY. THE COMPUTER TIME REQUIRED FOR A TYPICAL PROBLEM IS 40 MINUTES IF THE APPROXIMATE LOCATION OF THE MOST CRITICAL ARC CAN BE PREDICTED. OTHERWISE, THE TIME REQUIREMENT MAY BE CONSIDERABLY GREATER.

AS WITH ANY STABILITY ANALYSIS, THE UNDERSTANDING OF THE UNDERLYING ASSUMPTIONS AND THE CHOICE OF THE APPROPRIATE SHEAR STRENGTH PARAMETERS ARE ESSENTIAL TO THE OBTAINING OF A REALISTIC ANSWER TO THE PROPER EVALUATION OF THE RESULTS. NO ATTEMPT HAS BEEN MADE IN THIS REPORT TO GIVE THE READER THE NECESSARY BACKGROUND KNOWLEDGE OF SOIL MECHANICS.

## Introduction

A number of computer programs have been developed to reduce the time required for the stability analysis of slopes and embankment foundations. The program presented in this report is based on the program "Computer Solutions for Slope Stability Analysis - 9.2.020" written by the Corps of Engineers, U.S. Army Engineer District, Albuquerque, New Mexico, for the IBM 1620 computer. The following two operations, not possible with the original program, have been included in the present program:

1. The computation of the stability of an embankment on a foundation containing one or more incompletely consolidated soil layers (U is less than 100%).

2. An automatic search for the minimum factor of safety.

To do this without overrunning the available storage capacity and to shorten the computing time, the original program had to be modified considerably.

## Basis for Program

The slope stability analysis used in the program is the circular arc method using finite slices and containing the simplifying assumption that the resultant of forces on the side of a slice is zero. This analysis, although conservative in cases where the angle of internal friction is greater than zero, has the advantage of being much less complicated than more rigorous analyses when a number of soil layers with different strength characteristics are present.

New York State Department of Public Works uses the total stress method of stability analysis. The angle of internal friction and the cohesion for use in the computation of stability of embankments are determined from the total stress failure envelope for consolidated-undrained triaxial tests. To take into account the gradual strength gain of a saturated cohesive

FOUNDATION SOIL DUE TO CONSOLIDATION UNDER A SUPERIMPOSED LOAD, THE COMPONENT OF THE LOAD NORMAL TO THE FAILURE ARC IN THE FOUNDATION SOIL IS MULTIPLIED BY THE DEGREE OF CONSOLIDATION (U) OF THE SOIL. THE SUM OF THE NORMAL COMPONENT DUE TO THE SUPERIMPOSED LOAD TIMES THE DEGREE OF CONSOLIDATION AND THE NORMAL COMPONENT DUE TO PREEXISTING OVERBURDEN IS MULTIPLIED BY THE ANGLE OF INTERNAL FRICTION TO GIVE THE FRICTIONAL RESISTANCE.

THE DEGREE OF CONSOLIDATION IN SOIL MECHANICS IS GENERALLY COMPUTED WITH RESPECT TO THE CHANGE IN VOID RATIO. IT MUST BE KEPT IN MIND, HOWEVER, THAT THE RELATIONSHIP BETWEEN VOID RATIO AND EFFECTIVE STRESS AND STRENGTH IS LOGARITHMIC. AT INTERMEDIATE DEGREES OF CONSOLIDATION BETWEEN 0 AND 1.0, THE DEGREE OF CONSOLIDATION WITH RESPECT TO THE CHANGE IN VOID RATIO CAN BE CONSIDERABLY HIGHER THAN THE DEGREE OF CONSOLIDATION WITH RESPECT TO THE CHANGE IN EFFECTIVE STRESS AND STRENGTH. THEREFORE, THE TERM "DEGREE OF CONSOLIDATION (U)" AS USED IN THIS REPORT DESIGNATES THE RATIO OF THE EFFECTIVE STRESS INCREASE AT ANY TIME TO THE EFFECTIVE STRESS INCREASE AT FULL CONSOLIDATION.

THE SEARCH PATTERN FOR THE MOST CRITICAL FAILURE ARC IS BASED ON THE EXISTENCE OF "CONTOUR LINES" OF FACTORS OF SAFETY. POINTS ARE INVESTIGATED, GOING IN THE DIRECTION OF DECREASING FACTOR OF SAFETY, UNTIL A POINT IS FOUND WHERE THE FACTOR OF SAFETY IS LOWER THAN AT SURROUNDING POINTS.[1] THE SEARCH PATTERN IS DESCRIBED MORE COMPLETELY UNDER <u>SEQUENCE OF COMPUTATIONS</u>.

## <u>Capabilities and Limitations of Program</u>

THE PROGRAM CAN ANALYZE A CROSS-SECTION CONTAINING INCLINED AND DISCONTINUOUS FOUNDATION LAYERS, AN IRREGULAR GROUND SURFACE, AND BERMS. THE LIMITATIONS OF THE PROGRAM ARE AS FOLLOWS:

[1] HORN, J.A. "COMPUTER ANALYSIS OF SLOPE STABILITY" JOURNAL, SOILS MECHANICS AND FOUNDATIONS DIVISION, ASCE, VOL. 86, NO. SM3, JUNE 1960.

1. For use with the basic IBM 1620 computer (20,000 storage positions) the number of lines making up the cross-section is limited to ten, and the number of intersections between the failure arc and lines making up the cross-section is limited to fourteen. This means that a cross-section containing an embankment and continuous foundation layers would be limited to six foundation layers. If a berm were included, the number of foundation layers permissible would be reduced to five.

2. No vertical lines or lines having a slope greater than 500 on 1 should be used. If a vertical line constitutes a part of the free surface of the section, it should be approximated by a line with a steep slope. Otherwise, a vertical line between different zones in the section can be left out.

3. The maximum values which may be assigned to X-and Y-coordinates are plus or minus 9399.

4. The horizontal distance between the center of failure arc given in the input and the actual most critical center as determined by the computer cannot be greater than forty (40) feet.

5. Curved lines must be approximated by straight lines.

6. Seepage forces are not taken into account. However, their effect can be approximated by using in the seepage zone the saturated unit weight and a degree of consolidated (U) equal to the buoyant unit weight divided by the saturated unit weight. As explained later, the unit weight in this case must be written on the input form with a minus sign preceding it.

For a height of slope greater than ten feet the difference between the minimum factor of safety found by investigating points five feet apart, as in this program, and the minimum factor of safety found by investigating points one foot apart has been found during the development of this program to be less than five percent.

## Input Instructions

The following steps should be followed when preparing an input form for computer analysis:

1. Draw the section on cross-section paper so that the center of the most probable failure arc is to the right of the highest point on the ground surface.

2. NUMBER ALL LINES MAKING UP THE SECTION CONSECUTIVELY, STARTING WITH THE TOPMOST LINE AS NUMBER ONE. NO LINE SHALL, AT ANY POINT, BE DIRECTLY ABOVE A LOWER-NUMBERED LINE.

3. USING THE HIGHEST POINT ON THE GROUND SURFACE AS ORIGIN, ASSIGN COORDINATES TO THE ENDPOINTS OF, AND INTERSECTIONS BETWEEN, ALL LINES. X IS POSITIVE IN THE DIRECTION FROM THE ORIGIN TOWARDS THE ASSUMED CENTER OF THE FAILURE ARC, OR TO THE RIGHT. Y IS POSITIVE UPWARDS. THE Y-COORDINATES OF ALL LINES MAKING UP THE SECTION ARE ZERO OR NEGATIVE.

4. CHOOSE A STARTING FAILURE ARC. IN ORDER TO SAVE TIME IT IS DESIRABLE THAT THIS FAILURE ARC BE AS NEAR THE MOST CRITICAL ARC AS POSSIBLE. HOWEVER, SINCE IN THE SEARCH PATTERN THE Y-COORDINATE OF THE CENTER OF FAILURE ARC CANNOT BE DECREASED, THE STARTING CENTER SHOULD BE CHOSEN NOT HIGHER THAN THE LOWEST POSSIBLE POSITION OF THE MOST CRITICAL CENTER. ALSO, SINCE NO FAILURE ARC EXAMINED DURING THE SEARCH PATTERN IS SHALLOWER THAN THE STARTING FAILURE ARC, THE STARTING RADIUS SHOULD BE CHOSEN SO THAT THE STARTING FAILURE ARC IS NOT BELOW THE PROBABLE POSITION OF THE MOST CRITICAL ARC.

   IN A SOIL DERIVING MOST OF ITS STRENGTH FROM INTERNAL FRICTION, A SHALLOW FAILURE ARC WILL BE THE MOST CRITICAL; IN A SOIL DERIVING MOST OF ITS STRENGTH FROM COHESION, A DEEP FAILURE ARC WILL USUALLY BE THE MOST CRITICAL. FOR THIS REASON, IN A CASE WHERE A COHESIVE MATERIAL IS OVERLAIN BY A COHESIONLESS MATERIAL, IF THE STARTING FAILURE ARC LIES IN THE COHESIONLESS LAYER, THE COMPUTER USING THIS SEARCH PATTERN MAY FIND THE MOST CRITICAL CENTER FOR FAILURE IN THAT LAYER WITHOUT INVESTIGATING THE COHESIVE LAYER. TO PREVENT THIS, JUDGMENT MUST BE EXERCISED IN THE SELECTION OF THE STARTING FAILURE ARC.

   IN SOME CASES, SUCH AS THAT OF AN EMBANKMENT WITH A STABILIZING BERM, MORE THAN ONE "LOW SPOT" MAY EXIST ON THE SURFACE FORMED BY THE FACTOR OF SAFETY CONTOUR LINES, AND IT MAY BE DESIRABLE TO ANALYZE THE SECTION USING MORE THAN ONE INITIAL FAILURE ARC CENTER.

5. IF A THIN, LOW-STRENGTH SOIL LAYER IS PRESENT, THE STARTING RADIUS SHOULD BE SHOSEN SUCH THAT THE RADIUS PLUS A MULTIPLE OF FIVE FEET WILL FALL WITHIN THE LAYER.

6. FILL OUT THE INPUT DATA SHEET. WRITE DOWN THE NUMBER OF LINES IN THE SECTION. LIST THE COORDINATES OF EACH LINE AND THE SOIL PROPERTIES IN THE SOIL BELOW EACH LINE IN THEIR RESPECTIVE COLUMNS AFTER THE CORRESPONDING LINE NUMBER. WRITE IN THE APPROPRIATE SPACES THE COORDINATES AND RADIUS DEFINING THE STARTING FAILURE ARC. FOLLOWING IS AN EXPLANATION OF THE TERMS USED IN THE INPUT DATA SHEET:

N = NUMBER OF LINES

X1 = LEFT HORIZONTAL COORDINATE OF A LINE.

Y1 = LEFT VERTICAL COORDINATE OF A LINE.

X2 = RIGHT HORIZONTAL COORDINATE OF A LINE.

Y2 = RIGHT VERTICAL COORDINATE OF A LINE.

W = UNIT WEIGHT OF THE MATERIAL BELOW THE LINE. FOR SOILD BELOW THE GROUND WATER TABLE, THE BUOYANT UNIT WEIGHT SHOULD BE USED. IF A FOUNDATICN LAYER IS NOT FULLY CONSOLIDATED UNDER THE WEIGHT OF AN OVERLYING SOIL LAYER, THE UNIT WEIGHT OF THE OVERLYING SOIL LAYER IS WRITTEN WITH A MINUS SIGN IN FRONT OF IT.

F = TANGENT OF THE ANGLE OF INTERNAL FRICTION OF THE MATERIAL BELOW THE LINE.

C = COHESION OF THE MATERIAL BELOW THE LINE.

U = DEGREE OF CONSOLIDATICN, EXPRESSED AS A DECIMAL, IN THE MATERIAL BELOW THE LINE. THIS VALUE MUST BE FILLED IN FOR ALL SOILS IN THE SECTION.

H = HORIZONTAL COORDINATE OF THE STARTING FAILURE ARC CENTER.

G = VERTICAL COORDINATE OF THE STARTING FAILURE ARC CENTER.

R = STARTING RADIUS.

7. NEGATIVE NUMBERS MUST BE WRITTEN WITH A MINUS SIGN PRECEDING THEM; POSITIVE NUMBERS SHOULD BE WRITTEN WITH NO SIGN.

8. ALL INPUT DATA, EXCEPT THE NUMBER OF LINES (N) MUST BE WRITTEN WITH A DECIMAL POINT, AS SHOWN ON THE SAMPLE INPUT SHEET.

## SEQUENCE OF COMPUTATIONS

THE GENERAL SEQUENCE OF STEPS FOLLOWED BY THE COMPUTER IN FINDING THE MOST CRITICAL FAILURE ARC AND THE MINIMUM FACTOR OF SAFETY FOR A SLOPE ARE AS FOLLOWS:

1. THE INTERSECTION OF EACH LINE DEFINED BY THE ENDPOINT X AND Y COORDINATES RECEIVED ON THE INPUT CARDS, WITH THE FAILURE ARC, DEFINED BY THE HORIZONTAL AND VERTICAL COORDINATES OF THE CENTER AND BY THE RADIUS (H, G AND R), IS FOUND.

2. THE INTERSECTIONS ARE ARRANGED IN ORDER OF DECREASING MAGNITUDE OF X-COORDINATE AND NUMBERED.

3. EACH SEGMENT OF ARC WIDER THAN ONE-TENTH OF THE RADIUS IS DIVIDED INTO TEN "SLICES" OF EQUAL WIDTH. EACH SEGMENT OF ARC EQUAL TO OR SMALLER IN WIDTH THAN ONE-TENTH OF THE RADIUS IS DIVIDED INTO TWO "SLICES" OF EQUAL WIDTH.

4. THE Y-COORDINATES OF THE INTERSECTIONS OF THE CENTER-LINE OF THE SLICE AND THE LINES MAKING UP THE SOIL SECTION ARE DETERMINED.

5. THE WEIGHT OF EACH SLICE TO BE USED IN COMPUTING THE OVERTURNING FORCE IS COMPUTED BY MULTIPLYING THE Y-DISTANCE BETWEEN SUCCESSIVE INTERSECTIONS ON THE CENTERLINE BY THE SLICE WIDTH AND BY THE UNIT WEIGHT OF THE CORRESPONDING MATERIAL AND ADDING THE RESULTS FOR ALL PORTIONS OF THE CENTERLINE.

6. THE WEIGHT OF EACH SLICE TO BE USED IN COMPUTING THE NORMAL FORCE ON THE ARC IS COMPUTED. IN THE CASE OF COMPLETE CONSOLIDATION THIS WILL BE EQUAL TO THE WEIGHT COMPUTED FOR OVERTURNING FORCE. IF THE FAILURE ARE PASSES THROUGH A LAYER THAT IS NOT FULLY CONSOLIDATED, THE WEIGHT OF THE PORTION OF THE SLICE PASSING THROUGH THE LAYER OF SOIL UNDER THE ACTION OF WHICH INCOMPLETE CONSOLIDATION EXISTS IS MULTIPLIED BY THE DEGREE OF CONSOLIDATION (U).

7. THE COHESIVE FORCE ACTING ON THE BASE OF A SLICE IS COMPUTED BY MULTIPLYING THE UNIT COHESION (C) BY THE CHORD LENGTH OF THE BASE OF THE SLICE. THE ERROR INTRODUCED BY USING THE CHORD LENGTH INSTEAD OF THE ARC LENGTH IS LESS THAN ONE PERCENT.

8. THE OVERTURNING AND THE NORMAL COMPONENTS OF THE WEIGHT OF EACH SLICE ARE DETERMINED. THE FRICTION FORCE IS COMPUTED BY MULTIPLYING THE NORMAL COMPONENT BY THE ANGLE OF INTERNAL FRICTION.

9. AS THE COMPUTATIONS PROGRESS FROM SLICE TO SLICE, THE TOTAL OVERTURNING, FRICTION, AND THE COHESIVE FORCES ARE FOUND BY ADDING THEM CUMULATIVELY FROM SLICE TO SLICE.

10. THE FACTOR OF SAFETY IS COMPUTED BY DIVIDING THE SUM OF THE FRICTION AND THE COHESIVE FORCES BY THE OVERTURNING FORCE.

11. THE RADIUS IS INCREASED BY FIVE FEET AND STEPS ONE THROUGH ELEVEN ARE REPEATED TO FIND THE FACTOR OF SAFETY FOR THE NEW RADIUS. THIS IS REPEATED AS LONG AS EACH SUCCEEDING FACTOR OF SAFETY IS LOWER THAN THE PREVIOUS ONE. WHEN A FACTOR OF SAFETY LARGER THAN THE PRECEDING ONE IS FOUND,

THE PRECEDING FACTOR OF SAFETY AND THE X- AND Y-COORDINATES AND THE RADIUS OF THE FAILURE ARC ARE PUNCHED OUT. NEXT, THE X-COORDINATE OF THE FAILURE ARC CENTER IS INCREASED BY FIVE FEET, THE RADIUS IS SET EQUAL TO THE INPUT RADIUS AND THE LOWEST SAFETH FACTOR FOR THESE CENTER COORDINATES DETERMINED AND PUNCHED OUT. ADDITIONAL FAILURE ARC CENTERS ON A HORIZONTAL LINE ARE EXAMINED UNTIL THE MOST CRITICAL CENTER ON THAT LINE IS FOUND. THEN, ITS X-COORDINATE IS HELD CONSTANT, BIT ITS Y-COORDINATE INCREASED BY FIVE FEET AND THE MOST CRITICAL CENTER ON THAT HORIZONTAL LINE IS FOUND. THIS PROCESS IS CONTINUED UNTIL A POINT IS FOUND AT WHICH, IF IT IS ABOVE THE INPUT POINT, THE FACTOR OF SAFETY IS LOWER THAN AT ALL POINTS SURROUNDI G IT ON A FIVE FOOT GRID, HORIZONTALLY, VERTICALLY AND DIAGONALLY, EXCEPT THE GRID POINT FIVE FEET ABOVE AND FIVE FEET TO THE LEFT OF IT.

SLOPE STABILITY ANALYSIS

PROGRAM NUMBER #5171

SAMPLE PROBLEM

Job Transmittal Card

Cross Section Diagram

Source Sheet - SM-285 (9/63)

Output Listing

Output Cards

OCTOBER 1963

SAMPLE JOB TRANSMITTAL FORM

SLOPE STABILITY ANALYSIS

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Form EDP - 3a (7/63)

BUREAU OF EDP
JOB TRANSMITTAL CARD

| Control Identification Number |
| --- |
| |

Submitting Bureau or Unit SOIL MECHANICS Location BLDG. # 7

Date of Submission 0|9|0|2|6|3| by Joe Jones Ext. 2404

Date of Completion 0|9|0|6|6|3| Actual Completion Date | | | | | |

Job Title: SLOPE STABILITY ANALYSIS Procedure No. 5|1|7|1|0|2|

Remarks: ______

☒ Recurring
☐ Special

☒ Key Punch ☒ Tabulate ☐ Reproduce ☐ Sort
☐ Printing Punch ☐ Interpret ☐ Collate ☒ Compute

For further detailed instructions, see reverse side.

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SEE REVERSE SIDE OF THIS FORM FOR DETAILED INSTRUCTIONS

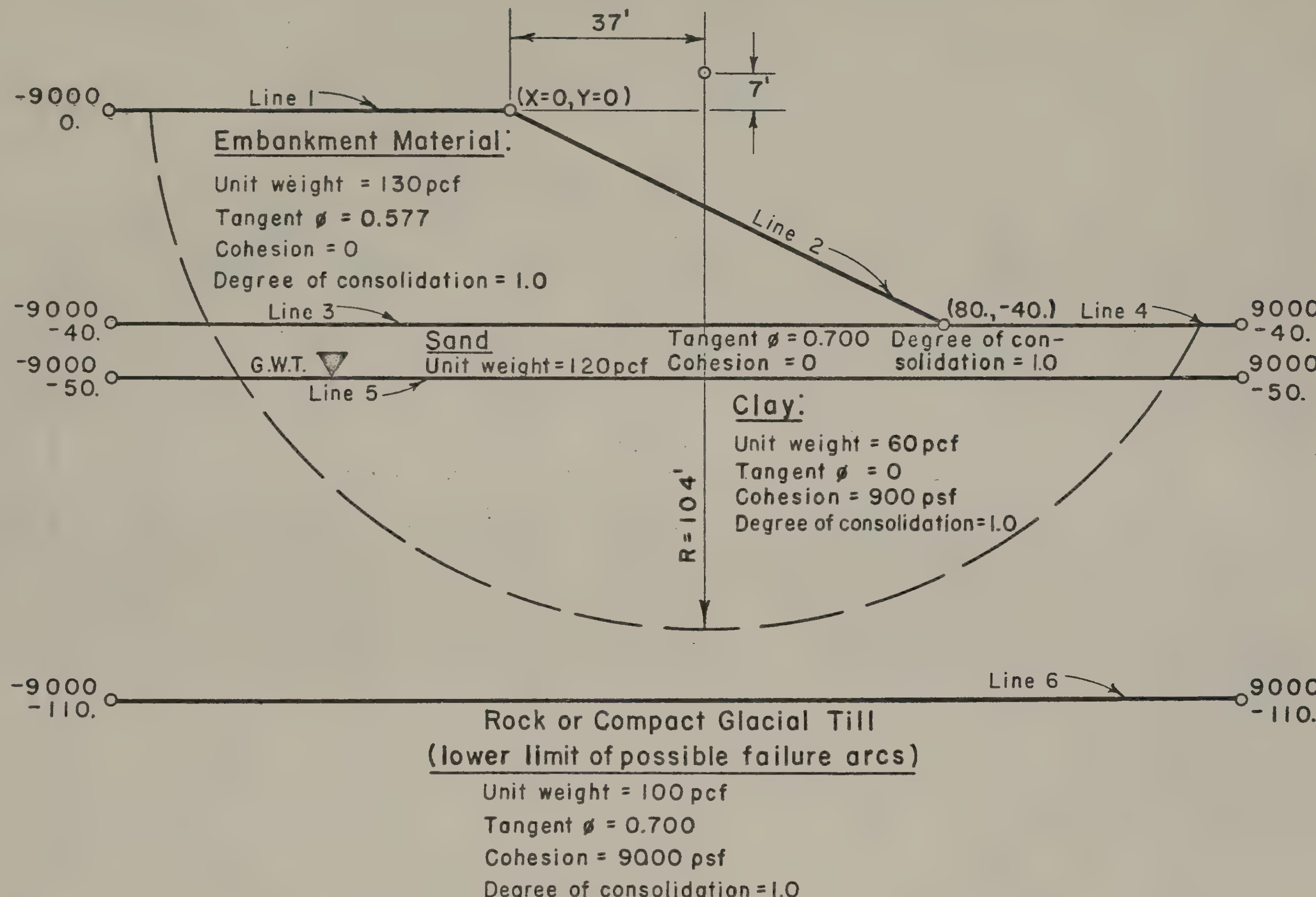


Figure No. 1
EMBANKMENT STABILITY COMPUTATION
TYPICAL EXAMPLE

M.O. SM 1640

STATE OF NEW YORK DEPARTMENT OF PUBLIC WORKS BUREAU OF SOIL MECHANICS

PROJECT SAMPLE PROBLEM Prepared by R. GODELL Date 10/3/63
STATION
ASSUMED CONDITIONS

# SLOPE STABILITY ANALYSIS
## PROGRAM NO. 5171 I.B.M. 1620 COMPUTER

CARD 1

| IDENT. NO. (1–9) | N (11–12) |
|---|---|
| 63-110-001 | 6 |

CARD TYPE 2

| LINE | X1 (1–6) | Y1 (10–14) | X2 (17–21) | Y2 (24–28) | W (30–34) | F (37–41) | C (44–48) | U (51–55) |
|---|---|---|---|---|---|---|---|---|
| 1 | -9000. | 0. | 0. | 0. | 130. | .577 | 0. | 1. |
| 2 | 0. | 0. | 80. | -40. | 130. | .577 | 0. | 1. |
| 3 | -9000. | -40. | 80. | -40. | 120. | .7 | 0. | 1. |
| 4 | 80. | -40. | 9000. | -40. | 120. | .7 | 0. | 1. |
| 5 | -9000. | -50. | 9000. | -50. | 60. | 0. | 900. | 1. |
| 6 | -9000. | -110. | 9000. | -110. | 100. | .7 | 9000. | 1. |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |

CARD 3

| H (1–4) | G (6–9) | R (11–14) |
|---|---|---|
| 37. | 7. | 104. |

CHECK BOX FOR COMMENTS ON REVERSE SIDE: ☐



SM-285 (9/63)

OUTPUT LISTING

#5171

SAFETY FACTOR

HORIZONTAL COORDINATE

VERTICAL COORDINATE

RADIUS

| IDENT.NO. | S.F. | H | G | R | |
|---|---|---|---|---|---|
| 63-10 -1 | .880 | 37.00 | 7.00 | 114.00 | ‡001 |
| 63-10 -1 | .906 | 42.00 | 7.00 | 114.00 | ‡002 |
| 63-10 -1 | .877 | 32.00 | 7.00 | 114.00 | ‡003 |
| 63-10 -1 | .905 | 27.00 | 7.00 | 114.00 | ‡004 |
| 63-10 -1 | .895 | 32.00 | 12.00 | 119.00 | ‡005 |
| 63-10 -1 | .882 | 37.00 | 12.00 | 119.00 | ‡006 |

NEW YORK STATE DEPARTMENT OF PUBLIC WORKS

SLOPE STABILITY ANALYSIS

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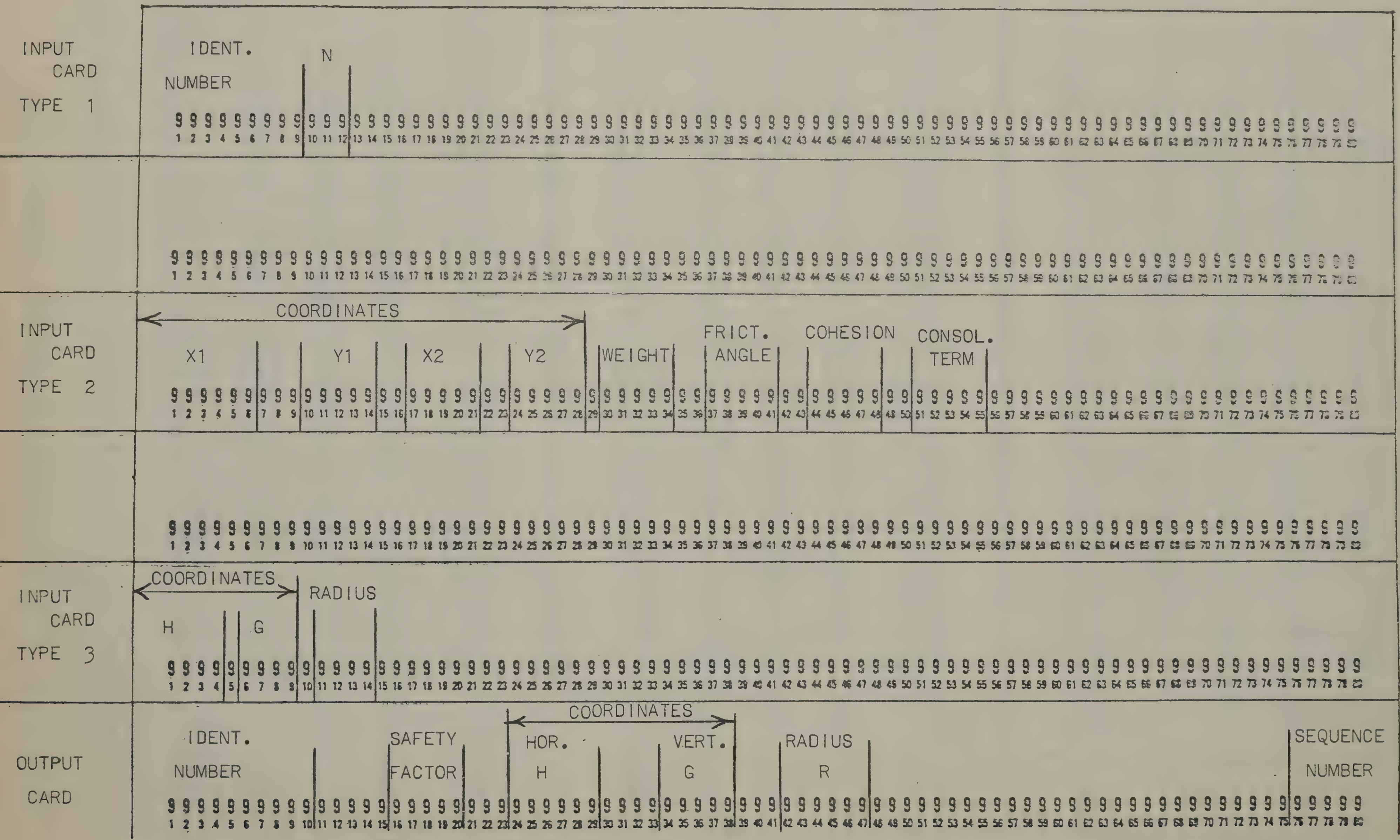
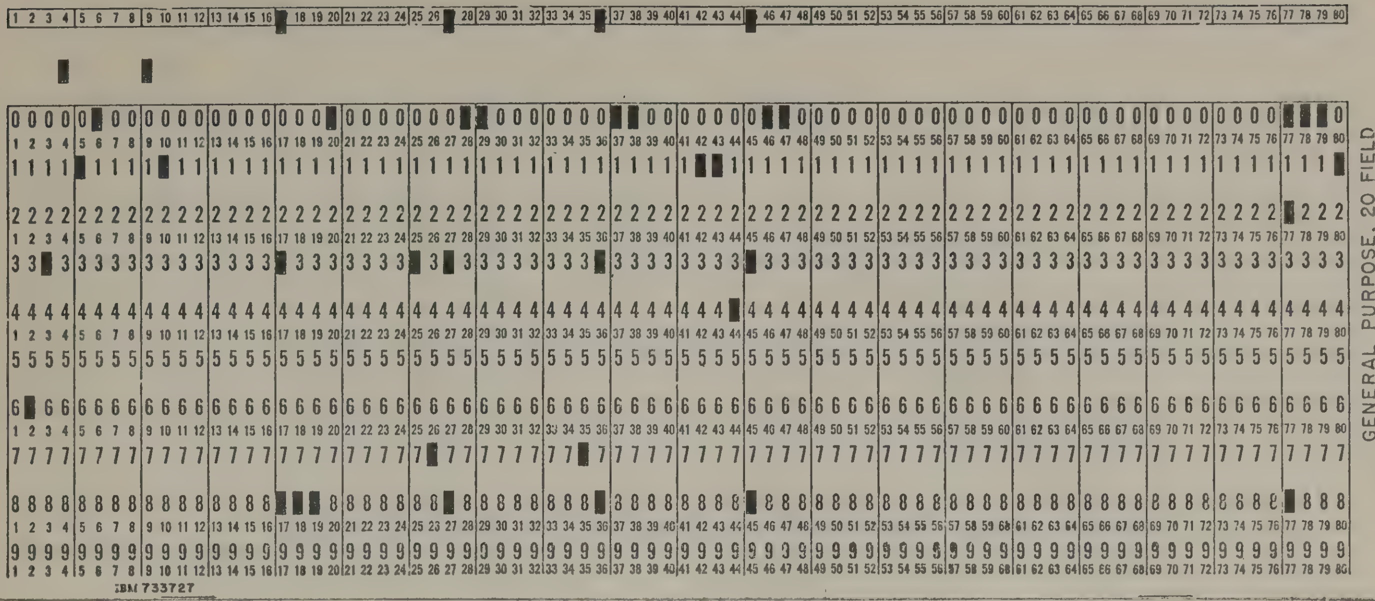
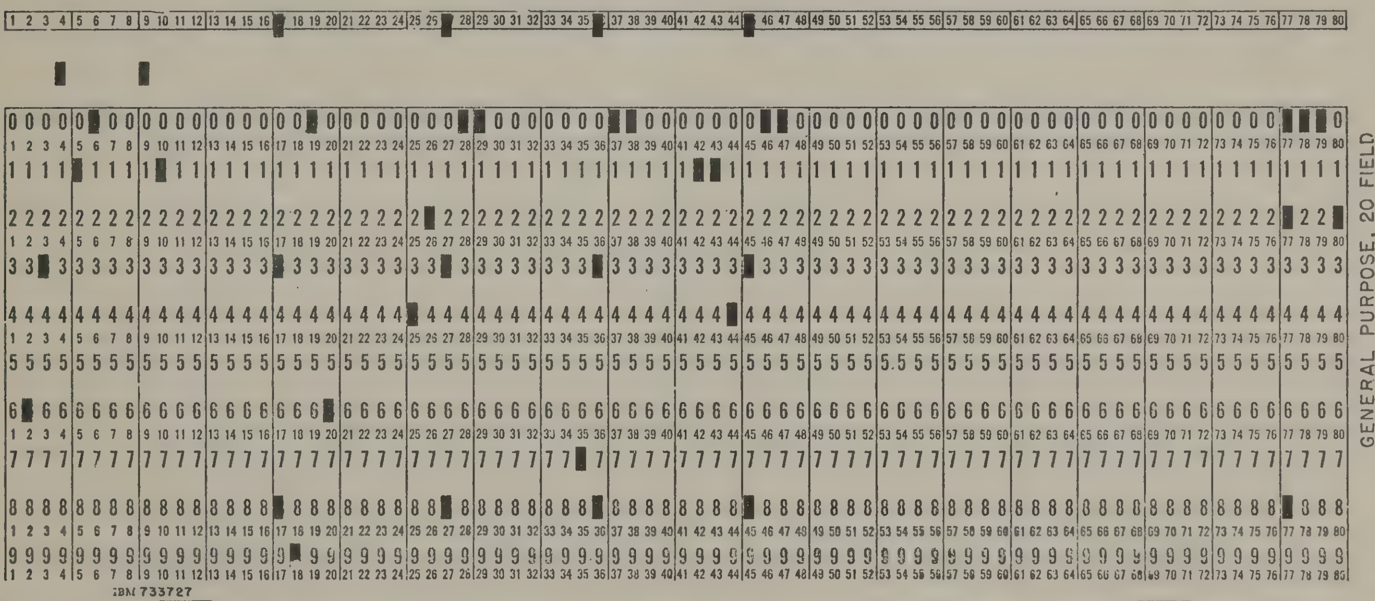
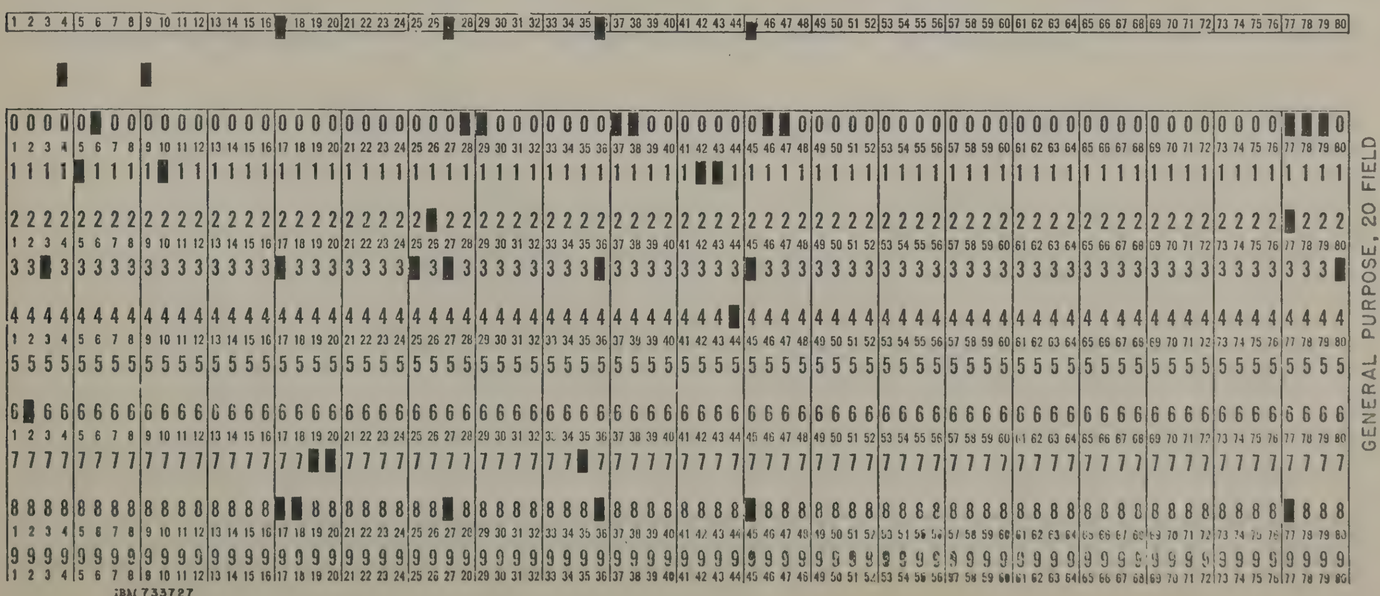


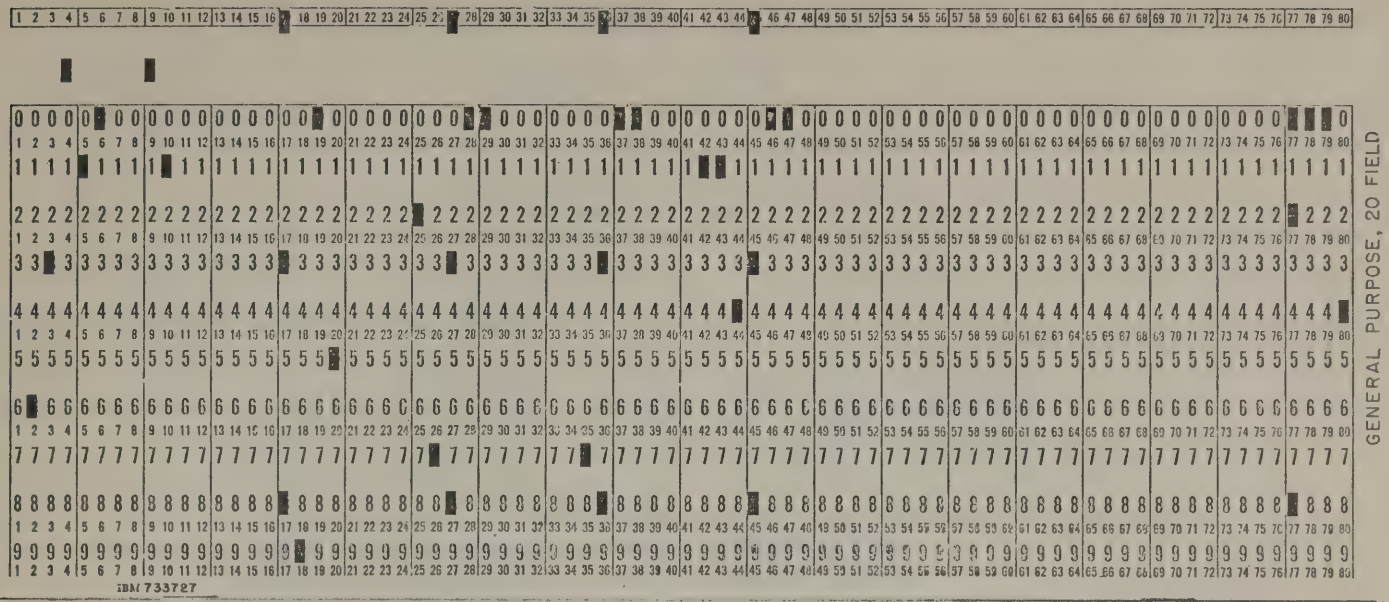
OUTPUT CARDS FOR SLOPE STABILITY ANALYSIS PROGRAM 5171

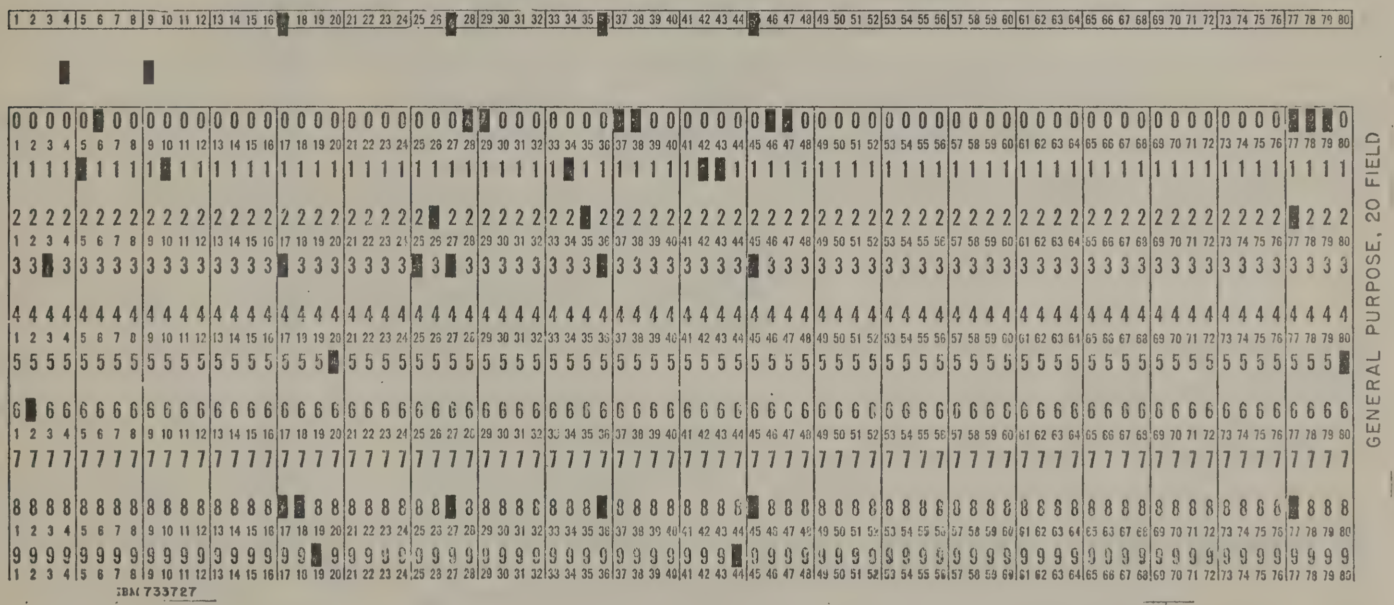


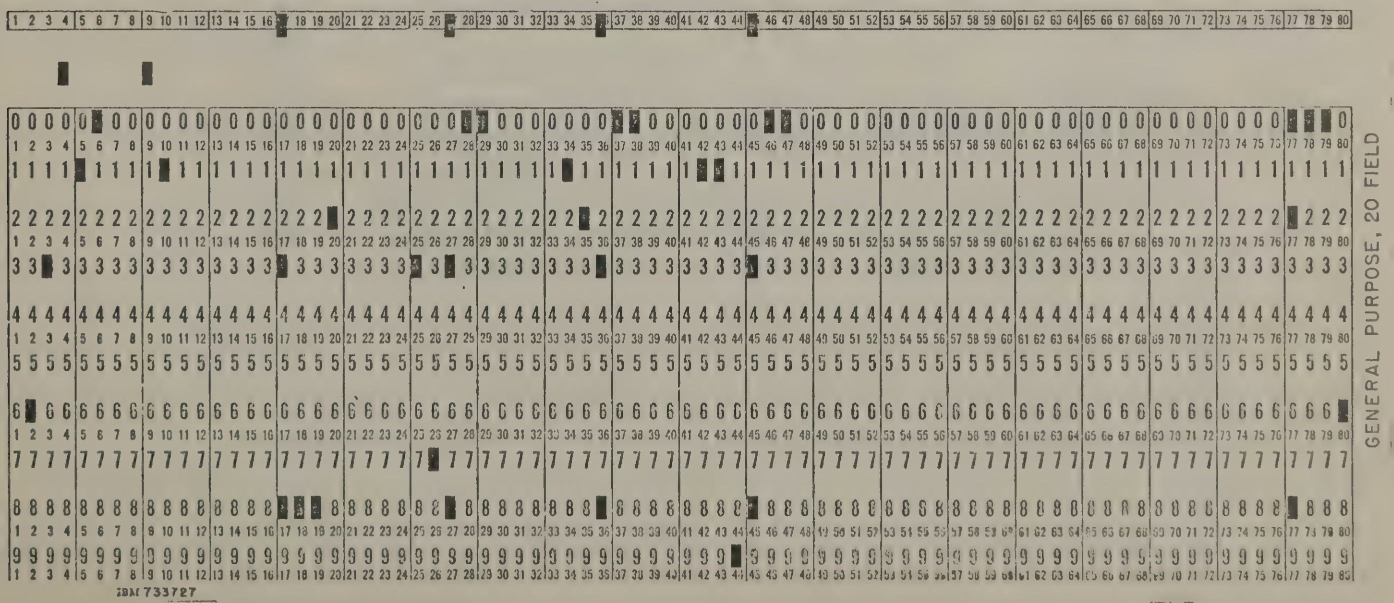



OUTPUT CARDS FOR SLOPE STABILITY ANALYSIS  PROGRAM 5171



SLOPE STABILITY ANALYSIS

PROGRAM # 5171

## Symbol Table

Before Instruction No. 212:

| | | |
|---|---|---|
| X1(n) | - | X coord. of 1st end point of line |
| Y1(n) | - | Y coord. of 1st end point of line |
| X2(n) | - | X coord. of 2nd end point of line |
| Y2(n) | - | Y coord. of 2nd end point of line |
| W(n) | - | Unit weight of material below line |
| F(n) | - | Friction coeef. below line |
| C(n) | - | Cohesion coeff. below line |
| AIX(n) | - | X coord. of unordered intersection |
| AIY(n) | - | Y coord. of unordered intersection |
| AAX(n) | - | X coord. of ordered intersection |
| N | - | Number of lines in cross-section |
| H | - | X coord. of center of failure arc |
| G | - | Y coord. of center of failure arc |
| R | - | Radius of failure arc |
| K | - | Index for counting number of unordered intersections |
| S | - | Slope of line |
| A | - | (quadratic formula) |
| B | - | (quadratic formula) |
| C | - | (quadratic formula) |
| D | = | $B^2 - 4(A)(C)$ |
| XC | - | Computed X coord. of simutaneous solution of circle and straight line |
| NN | - | Index for counting number of ordered intersections |
| AYX | - | Y coordinate |
| YC | - | X coordinate |
| FS(n) | - | lowest factor of safety for failure arc centers on a horizontal line |
| IY | - | |
| ID | - | Identification No. |
| NO | - | |
| RI | - | Initial radius |
| U(n) | - | Degree of consolidation of material below line |
| MQ | - | Index for counting failure arcs having the same center |
| MN | - | Index for counting failure arcs centers |
| SF | - | Present lowest factor of safety |
| AL | - | Index used in ordering intersections |

SLOPE STABILITY ANALYSIS

PROGRAM # 5171

## Symbol Table

After Instruction No. 212 (note - variables remaining the same are not redefined)

| | |
|---|---|
| B | - Summation of cohesion forces |
| SD | - Summation of tangential or driving forces |
| XC | - Summation of frictional forces |
| C | - Chord length between successive intersections on arc |
| S | - Cohesion force for an increment of arc |
| WD | - Slice width |
| XB | - Dist. from origin to centerline of slice |
| SN | - Summation of normal weight components (per arc segment) |
| J | - Index for counting number of slices (10 per arc segment) |
| YA | - Y distance to bottom of slice on center line |
| K | - Index for counting number of ordered intersections on centerline of slice |
| YC | - Y coord. of intersection on centerline of slice |
| AIY(K) | - Y coord. of ordered intersections on centerline of slice |
| AIX(K) | - Unit weight of material associated with unordered intersections on centerline |
| AIF(K) | - Y coord. of ordered intersections on centerline of slice |
| AIC(K) | - Unit weights associated with ordered intersections |
| ACC | - Total weight of slice |
| AFF | - Summation of frictional forces per segment of arc |
| A | - Factor of safety |
| AIU(K) | - Degree of consolidation associated with ordered intersections |
| ACD | - Weight of slice for computing normal forces |
| L | - Used as index for computed go to |
| WUI | - Unit weight associated with ordered intersections on centerline of slice |
| JN | - Index for counting intersections on centerline of slice |
| REP | - Weight of segment of slice |
| YAA | - Y distance to bottom of slice |
| AB | - Factor of safety stored for comparison |
| RR | - Radius of the most critical failure arc at a center |

SLOPE STABILITY ANALYSIS

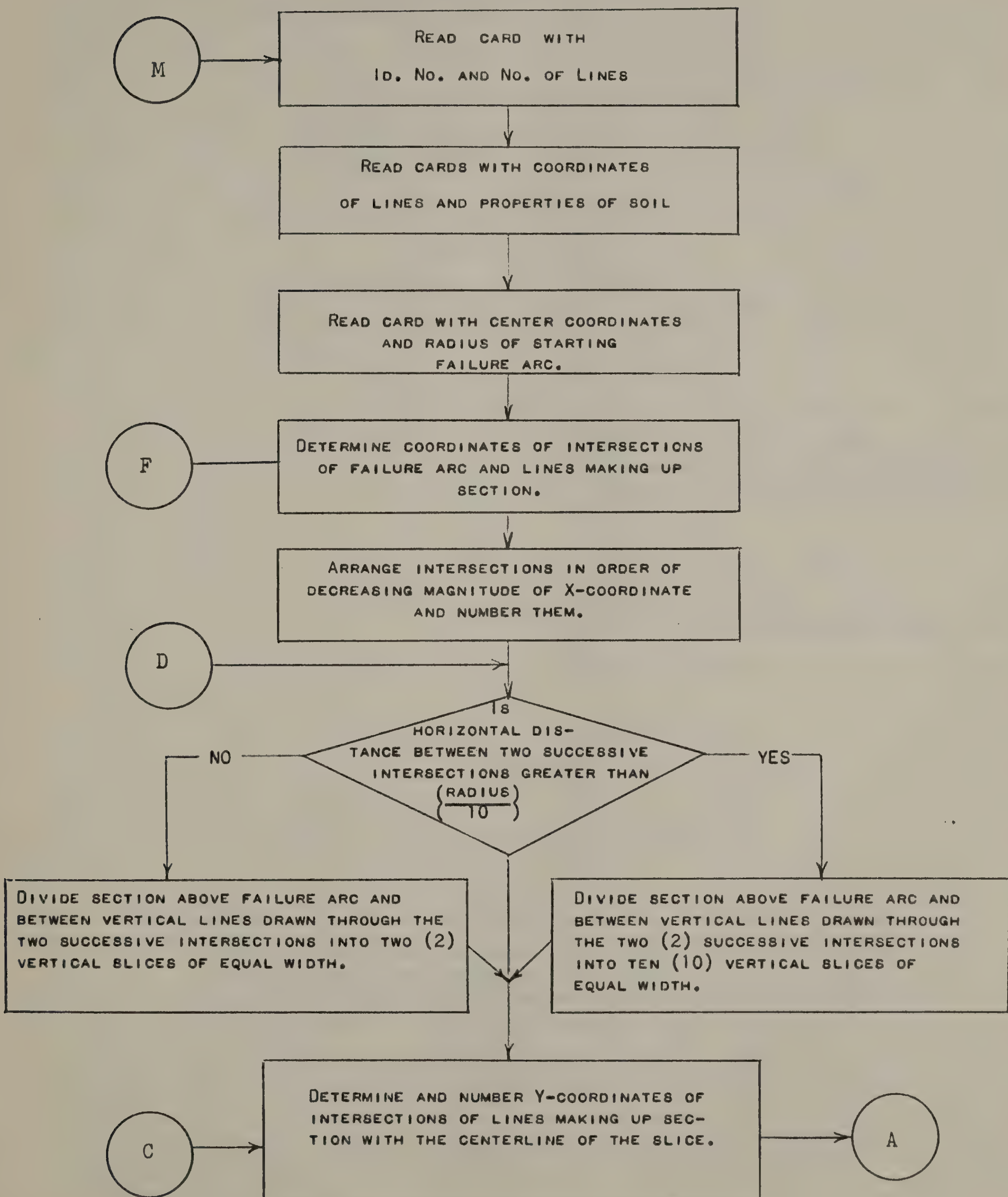
PROGRAM # 5171

BLOCK DIAGRAM

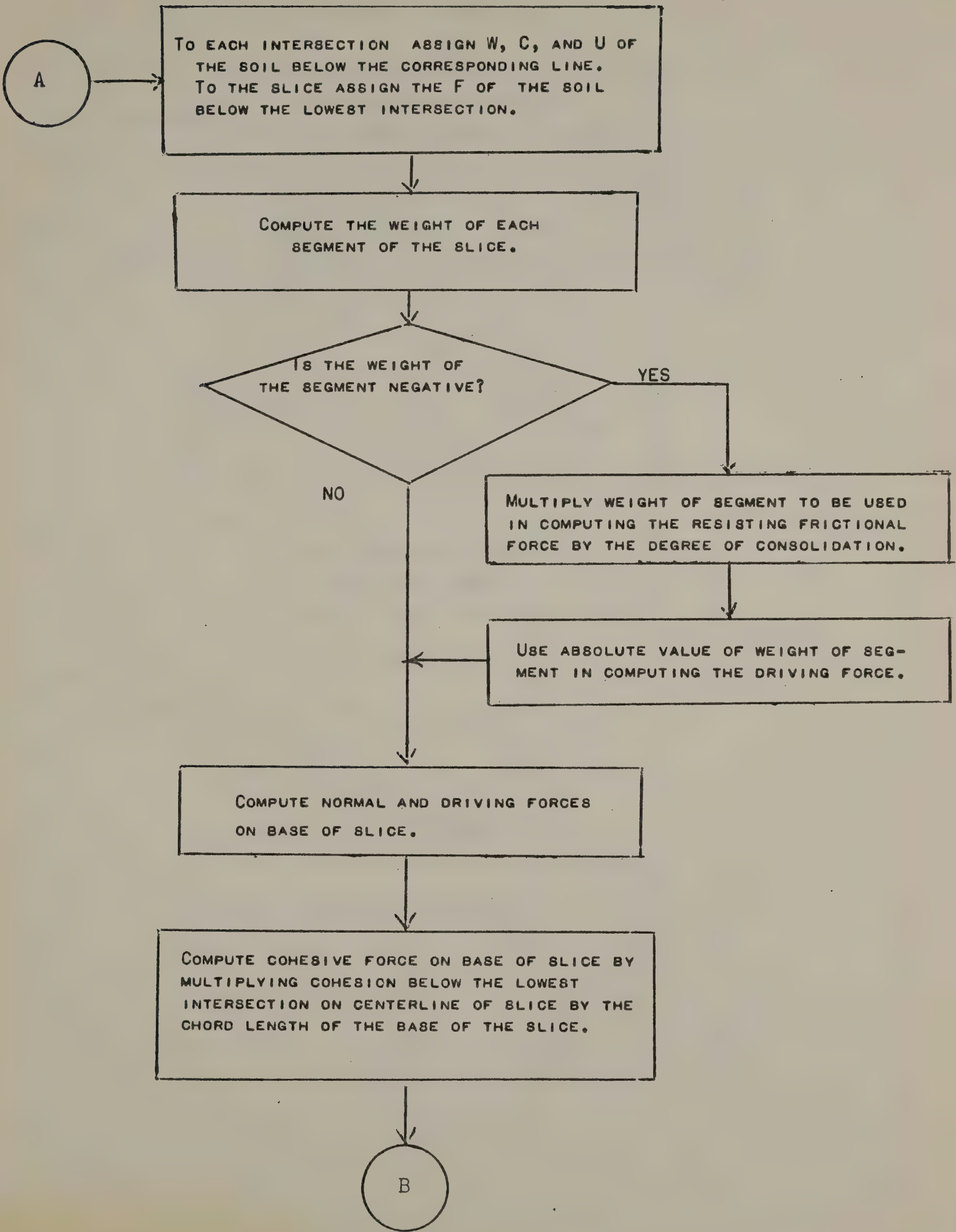
OCTOBER 1963

# SLOPE STABILITY ANALYSIS

## BLOCK DIAGRAM

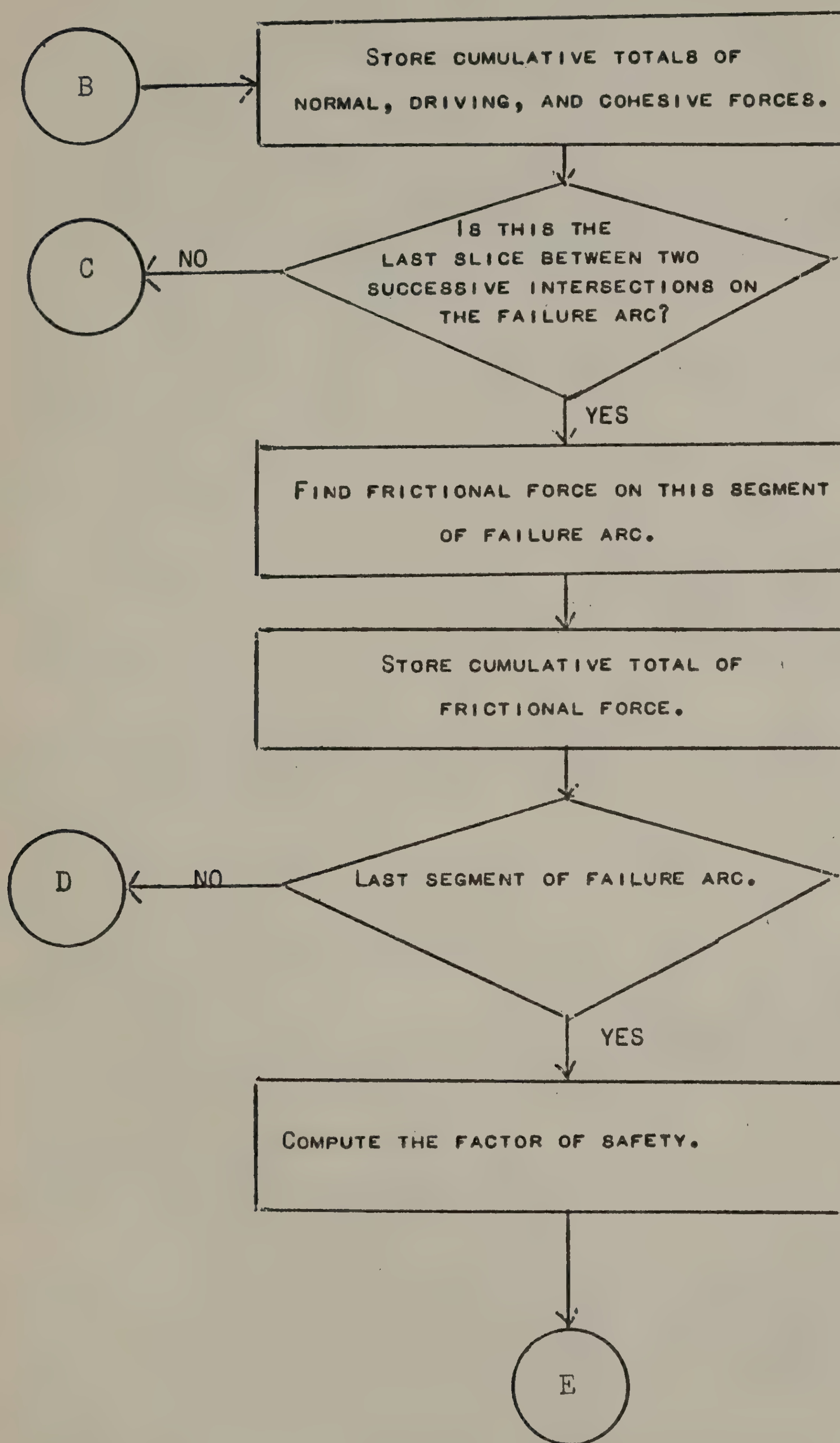


# SLOPE STABILITY ANALYSIS
## BLOCK DIAGRAM



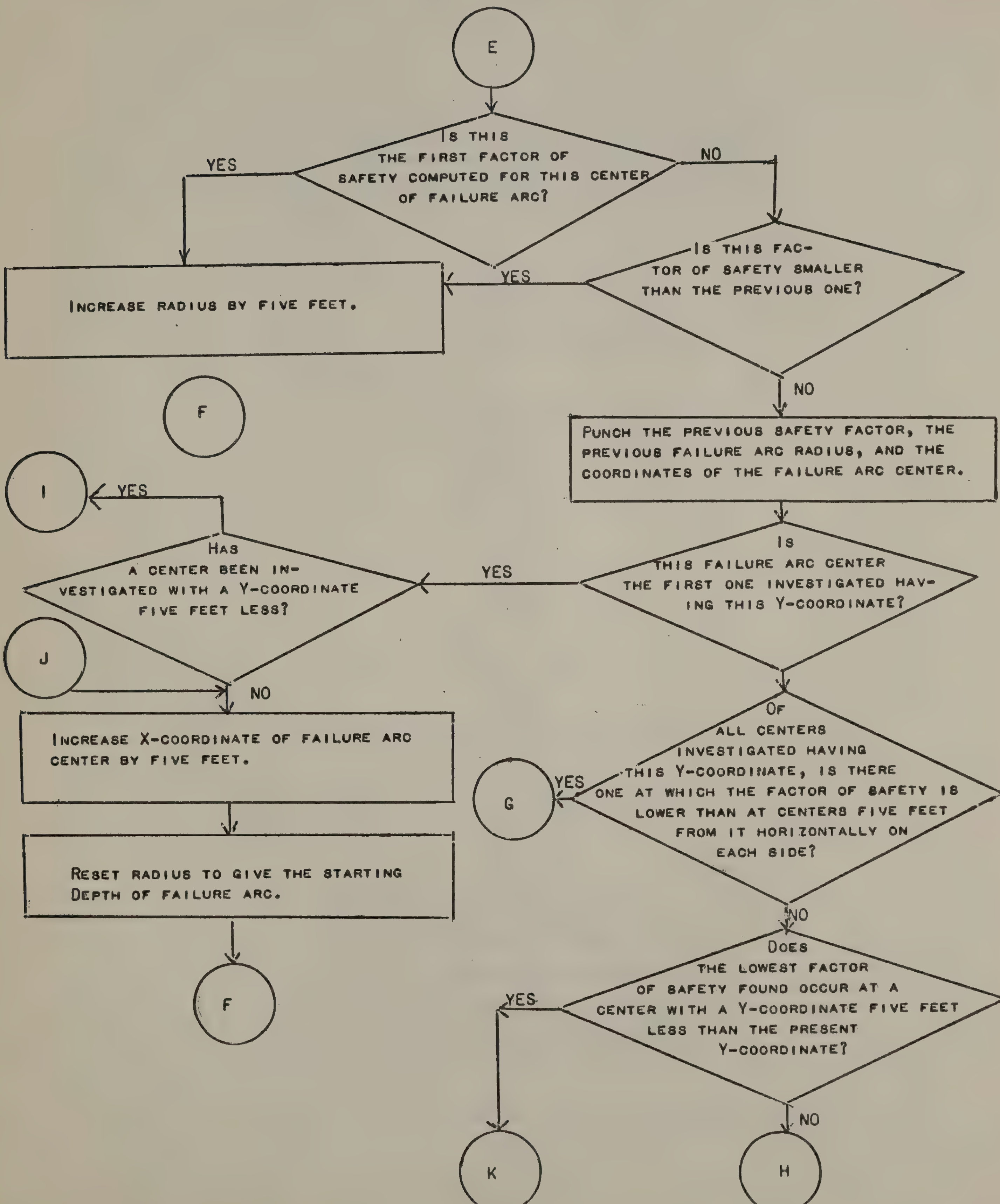
SLOPE STABILITY ANALYSIS

BLOCK DIAGRAM



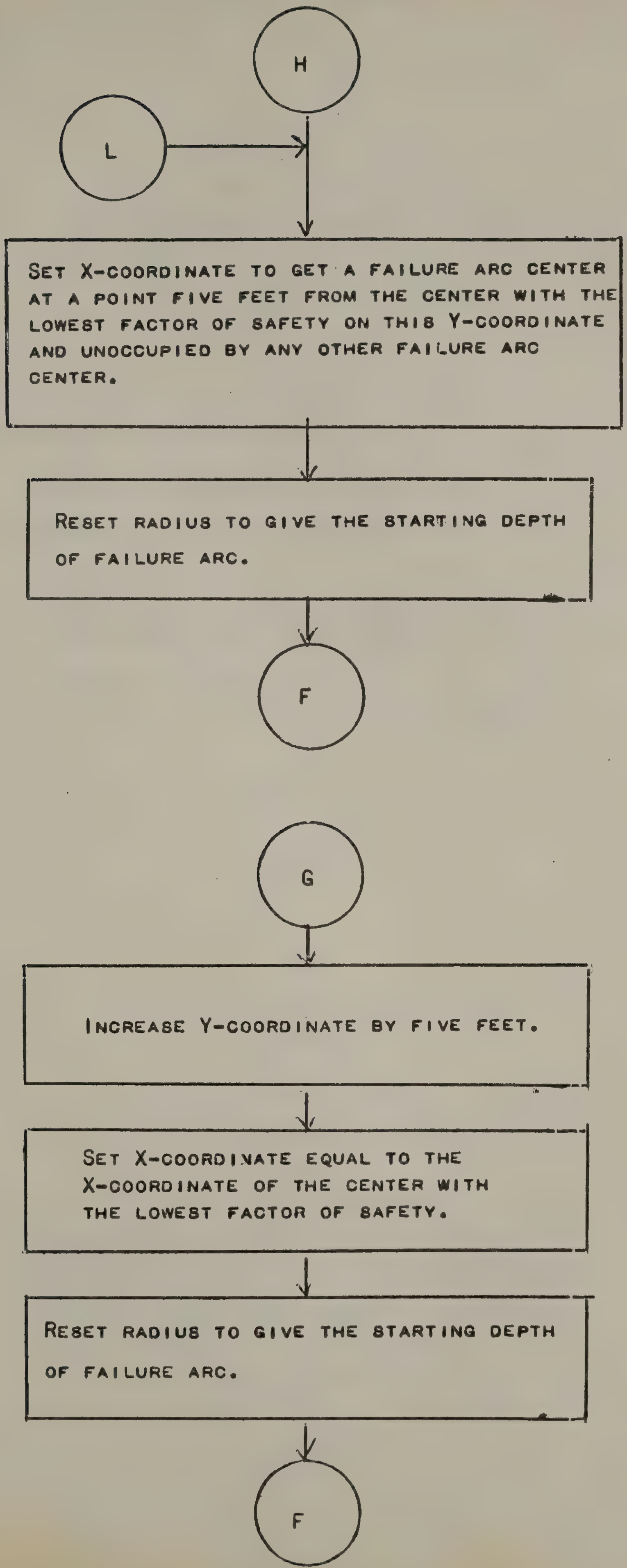
SLOPE STABILITY ANALYSIS

BLOCK DIAGRAM



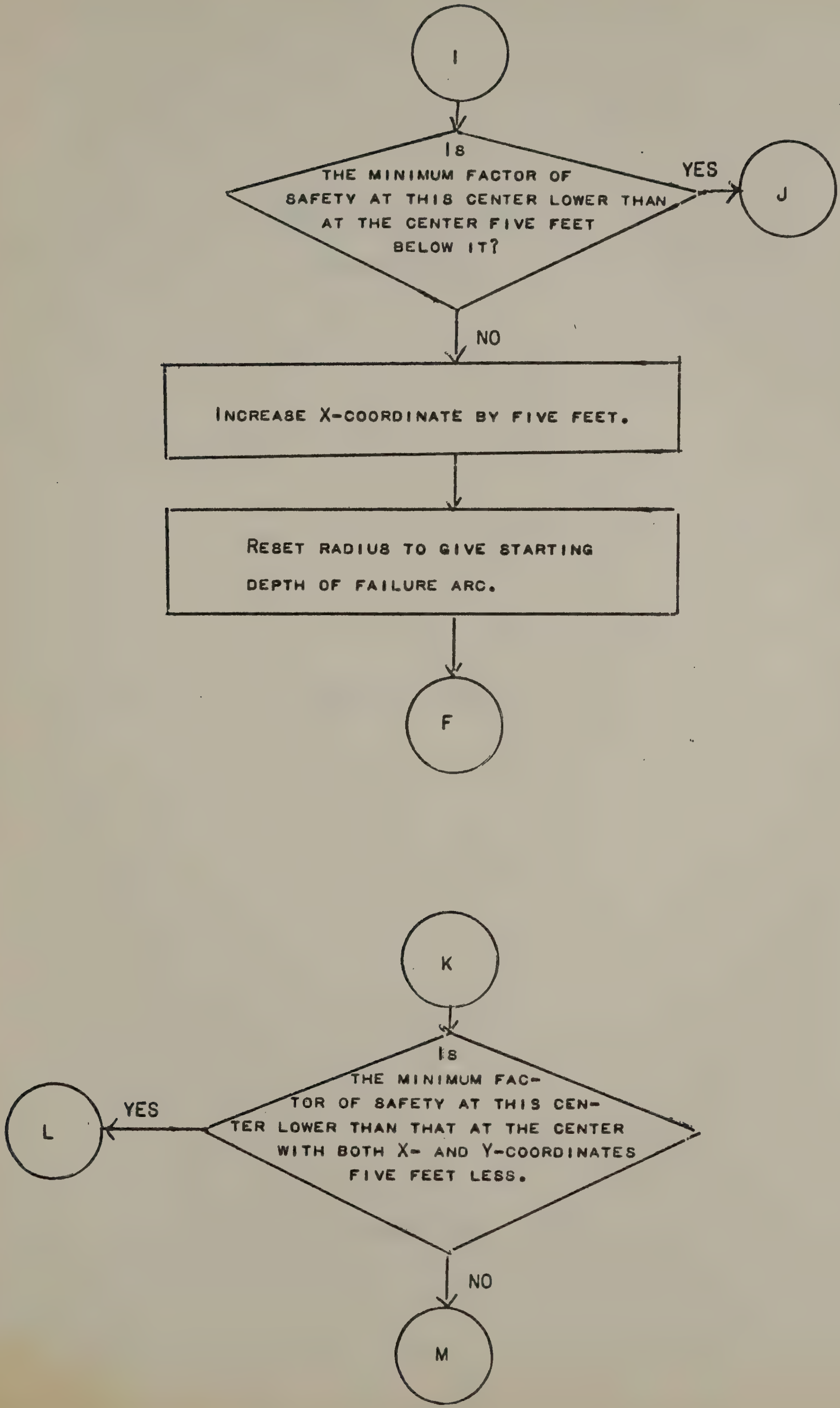
SLOPE STABILITY ANALYSIS

BLOCK DIAGRAM



SLOPE STABILITY ANALYSIS

BLOCK DIAGRAM



SLOPE STABILITY ANALYSIS

PROGRAM # 5171

FORTRAN LISTING

OCTOBER 1963

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C     SLOPE STABILITY ANALYSIS WITH SEARCH PATTERN (REVISED)  5171
      DIMENSION X1(10),X2(10),Y1(10),Y2(10),W(10),F(10),U(10)
      DIMENSION AAX(14),FS(10)
      DIMENSION C (10)          ,AIX(14),AIY(14),AIF(14),AIC(14),AIU(14)
    2 READ 45,IY,ID,NO,N
   45 FORMAT (I2,I3,I4,I4)
   46 FORMAT (F8.1,F8.1,F8.1,F8.1,F8.3,F8.3,F8.0,F8.3)
   47 FORMAT (F8.1,F8.1,F8.1)
      DO 5 I=1,N
    5 READ 46,X1(I),Y1(I),X2(I),Y2(I),W(I),F(I),C(I),U(I)
    4 READ 47,H,G,R
      RI=R
      MQ=0
      MN=2
      SF=9999.
   10 K=0
      MQ=MQ+1
      DO 140 I=1,N
      AYX=Y1(I)
      YC=X1(I)
      S=(Y2(I)-AYX)/(X2(I)-YC)
      A=S**2+1.
      B=2.*(S*(AYX-S*YC-G)-H)
      Q=S*YC*(S*YC-2.*AYX+2.*G)
      Q=Q+G*(G-2.*AYX)+H*H+AYX*AYX-R*R
      D=B**2-4.*A*Q
      IF(D)140,140,116
  116 AL=1.
  401 XC=(AL*SQRT(D)-B)/(2.*A)
      IF(X2(I)-XC)119,124,119
```

```
119 IF((YC-XC)/(X2(I)-XC))124,124,134
124 K=K+1
    AIX(K)=XC
    AIY(K)=S*XC-S*YC+AYX
134 IF(AL)140,400,400
400 AL=-1.
    GO TO 401
140 NN=1
201 AAX(NN)=-9400.
202 DO 210 I=1,K
    IF(AAX(NN)-AIX(I))203,204,210
204 AIX(I)=-9500.
    NN=NN+1
    GO TO 201
203 AAX(NN)=AIX(I)
210 CONTINUE
    IF(NN-K)202,212,212
212 NN=NN-1
    B=0.
    SD=0.
    YC=0.
    XC=0.
    DO 900 I=1,NN
    WD=(AAX(I)-AAX(I+1))*.1
    XB=AAX(I)-WD*.5
    SN=0.
    DO 891  J =1,10
    IF((AAX(I)-AAX(I+1))-R*.1)214,214,216
214 IF(J-1)213,213,215
```

```
215 IF(J-9)891,891,216
213 WD=5.*WD
    XB=AAX(I)-WD*.5
216 YA=G-SQRT(R**2-(H-XB)**2)
    K=0
    DO 603 L=1,N
    IF(X2(L)-XB)603,600,591
591 IF(XB-X1(L))603,600,600
600 YC=((Y1(L)-Y2(L))/(X1(L)-X2(L)))*(XB-X1(L))+Y1(L)
    IF (YC-YA) 603,602,602
602 K=K+1
    AIY(K)=YC
    AIF(K)=F(L)
    AIU(K)=U(L)
    AIC(K)=C(L)
    AIX(K)=W(L)
603 CONTINUE
    AIF(I)=AIF(K)
    AIU(J)=AIU(K)
    AIC(J)=AIC(K)
    AIY(K+1)=YA
    ACC=0.
    ACD=0.
    DO 807 JN=1,K
    WUI=AIX(JN)
    REP=WD*WUI*(AIY(JN)-AIY(JN+1))
    IF(WUI)806,806,805
806 REP=-REP
    ACD=ACD+AIU(J)*REP
    GO TO 807
```

```
805 ACD=ACD+REP
807 ACC=ACC+REP
    SN=SN+(G-YA)*ACD/R
    SD=SD+(H-XB)*ACC/R
    IF(AIC(J))890,880,880
880 IF(J-1)881,881,882
882 IF(J-10)883,884,884
881 S=AIC(J)*SQRT((WD/2.)**2+(YA-G+SQRT(R**2-AAX(I)**2))**2)
885 B=B+S
    YAA=YA
    GO TO 890
883 S=AIC(J)*SQRT(WD**2+(YAA-YA)**2)
    GO TO 885
884 AAX(I)=AAX(I+1)
    S=AIC(J)*SQRT(WD**2+(YAA-YA)**2)
    B=B+S
    GO TO 881
890 XB=XB-WD
891 CONTINUE
    AFF=SN*AIF(I)
    XC=XC+AFF
900 CONTINUE
    A=(B+XC)/SD
    IF (MQ-1)19,19,12
  9 MN=MN+1
    MQ=0
    GO TO 10
 19 AB=A
    R=R+5.
```

```
      GO TO 10
   12 IF (A-AB)19,19,22
   22 FS(MN)=AB
      RR=R-5.
      PUNCH 40,IY,ID,NO,FS(MN),H,G,RR
      IF (MN-3)88,88,24
   88 GO TO (25,23,17),MN
   25 IF (FS(MN)-SF)21,21,20
   20 GO TO 2
   21 MN=3
      FS(MN)=FS(1)
      FS(MN-1)=FS(2)
      GO TO 17
   23 IF (FS(MN)-SF)27,27,26
   27 H=H+5.
 1000 R=RI
      GO TO 9
   26 MN=0
      GO TO 27
   17 IF (FS(MN)-FS(MN-1))27,27,28
   28 H=H-10.
      GO TO 1000
   24 IF (FS(3)-FS(2))30,30,29
   29 IF (MN-4)31,31,32
   31 IF (FS(MN)-FS(MN-2))34,34,35
   32 IF(FS(MN)-FS(MN-1))34,34,37
   35 SF=FS(MN-2)
      GO TO 36
   37 SF=FS(MN-1)
   36 H=H+5.
```

```
1001 G=G+5.
     RI=RI+5.
     MN=1
     GO TO 1000
  34 H=H-5.
     GO TO 1000
  30 IF (FS(MN)-FS(MN-1))27,27,38
  38 H=H-5.
     SF=FS(MN-1)
     GO TO 1001
  40 FORMAT (I3,I3,I4,F10.3,F9.2,F9.2,F9.2)
     END
```

SLOPE STABILITY ANALYSIS

PROGRAM NUMBER 5171

## EXPLANATION OF TERMS

UNIT GROUPING　　　　　　　　　　CARD #1

| Name | Field | Columns | Explanation |
|---|---|---|---|
| Year | XX | 1 - 2 | Year of Test |
| — | X | 3 | Minus Punch |
| District | XX | 4 - 5 | District Number |
| — | X | 6 | Minus Punch |
| Number | XXX | 7 - 9 | Test Sequence Number |
| N | XX | 11 - 12 | Number of Lines in Cross Section |

SLOPE STABILITY ANALYSIS

PROGRAM NUMBER 5171

## EXPLANATION OF TERMS

UNIT GROUPING — CARD TYPE 2

| Name | Field | Columns | Explanation |
|---|---|---|---|
| X1 | *XXXX. | 1 - 6 | LT. Horizontal Coordinate of Line |
| Y1 | *XXX. | 10 - 14 | LT. Vertical Coordinate of Line |
| X2 | *XXX. | 17 - 21 | RT. Horizontal Coordinate of Line |
| Y2 | *XXX. | 24 - 28 | RT. Vertical Coordinate of Line |
| W | *XXX. | 30 - 34 | Weight of Material (P.C.F.) |
| F | X.XXX | 37 - 41 | Friction Angle in Degrees |
| C | XXXX. | 44 - 48 | Cohesion |
| U | X.XXX | 51 - 55 | Consolidation Ratio |

* DENOTES EITHER A BLANK OR A -

SLOPE STABILITY ANALYSIS

PROGRAM NUMBER 5171

## EXPLANATION OF TERMS

UNIT GROUPING | CARD TYPE 3

| Name | Field | Columns | Explanation |
|---|---|---|---|
| H | XXX. | 1 - 4 | Horizontal Coördinate of Radius |
| G | XXX. | 6 - 9 | Vertical Coordinate of Radius |
| R | XXX. | 11 - 14 | Radius |